Search for $WH \rightarrow WWW \rightarrow l^\pm l'^\pm \nu \nu' + X$ at DØ detector

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on behalf of DØ collaboration
DPF 2006
Tevatron Collider

- $p\bar{p}$ Collider with $\sqrt{s} = 1.96\text{TeV}$
- Two experiments: CDF and DØ
- Run I $\int L dt \sim 125 \text{ pb}^{-1}$
- Run II currently $> 1 \text{ fb}^{-1}$
- Run II expected: 4 - 8 $\text{ fb}^{-1}$
DØ Detector at Tevatron

- Silicon microstrip tracker (SMT)
- Scintilating Fiber tracker
- 2 Tesla solenoid
- Liquid argon Calorimeter
- 3 layers of muon scintillator and wire chambers

DØ Run II tracking system
Why this channel is interesting?

- $H \rightarrow W W^*$ decay mode dominates SM Higgs masses above 135 GeV.

- In fermiophobic Higgs models $\text{Br}(H \rightarrow W W^*)$ may be close to 100% for Higgs masses as low as 100 GeV.

- $H \rightarrow bb$ mode suffer from $Wbb$ background.

- Have smaller physical backgrounds than direct Higgs production $pp \rightarrow H \rightarrow W W^*$ which suffer from $Z/\gamma^*$, $WW$ and ttbar production.
WH → WWW → \( l^\pm v l'^\pm v' \) + X signature

- 2 high-\( P_T \) like-sign leptons (e,\( \mu \))
- Missing transverse energy (\( ME_T \)) from neutrinos

Physical backgrounds are:
- WZ → \( l^\pm v l'^\pm v' \)
- ZZ → \( l l' l' \)
- Triple vector boson: VVV (V=W,Z)
- \( t\bar{t} + V \)

These are negligible backgrounds
Event selection

- Di-lepton Trigger (ee, eμ, μμ)
- 2 like sign leptons $P_T > 15$ GeV

**Electron:**

- Central calorimeter (CC) electron ($|\eta_{det}| < 1.5$)
- Standard EM cuts: iso<0.15, emf>0.9
- Calorimeter shower shape consistent with electron (Lhood>0.85)
- Spatial and momentum match between track and EM cluster

**Muon:**

- “loose” quality with central track match
- passes cosmic veto
- Doesn’t share its track with an electron candidate
- Jet isolation: $\Delta R(\mu, j) > 0.5$
- Track and calorimeter isolation
Instrumental backgrounds

1. “Charge flips” (charge mismeasurement of one of the leptons). Same-flavor channels (ee, $\mu\mu$) are dominated by $Z/\gamma^*$. 

3. Like-sign lepton pairs from multijet and $W+$jets production
   In the case of muons, these can be:
   • real muon from heavy flavor jets 
   • punch-through hadrons 
   • muons from $\pi/K$ decays 
   In the case of electrons it is:
   • heavy flavor decay to electron 
   • Hadrons misidentified as electrons
In order to reduce instrumental background tighter track cuts applied

Tracks required:

• Have at least 2 SMT (Silicon Microstrip Tracker) and 5 CFT (Central Fiber Tracker) hits

• A small distance of closest approach (DCA) to the beam axis $|dca|<0.1\text{cm}$

• A small distance between Z-position of the lepton track at DCA and event primary vertex (PV) $\Delta Z(l,PV)<1\text{cm}$. 

• A small DCA significance $|dca/\sigma(dca)|<3$
Background estimation

- "Physical" ($ZZ, WZ$) normalized on theoretical cross-section
- QCD and "charge flips" fractions are estimated by fitting lepton invariant mass ($M_{ll}$) in data using:
  - QCD shape derived from data sample where e or $\mu$ or both fail isolation/likelihood cuts.
  - "Charge flips" probability curve (as a function of lepton $P_T$) taken from MC simulation of W and Z decays.
  - To avoid bias from potential signal fit is performed on the sample of events which failed TLD cut.
Topological likelihood discriminant

In order to improve S/B ratio final selections based on topological likelihood discriminant (TLD):

$$\text{lhs}(v_1, \ldots, v_n) = \frac{\prod_i s_i(v_i)}{\prod_i s_i(v_i) + \prod_i b_i(v_i)}$$

Where $s_i(v_i)$ and $b_i(v_i)$ are signal and background probability density of variable $v_i$

Topological variables are following:

• Opening angle $\Delta \phi_{\mu\mu}$ ($\mu\mu$ channel)
• $ME_T$ (ee, $e\mu$ channels)
• Hadronic $ME_T$ ($ME_T$ not corrected for leptons) (all channels)
Dilepton Mass fit for $ee$ and $\mu\mu$

D0, 360 pb$^{-1}$

D0, 380 pb$^{-1}$
TLD cut is optimized for best expected limit for each higgs mass and channel (ee, $\mu\mu$, $e\mu$) individually:

<table>
<thead>
<tr>
<th>$M_H$</th>
<th>ee</th>
<th>$e\mu$</th>
<th>$\mu\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>115</td>
<td>0.8</td>
<td>0.39</td>
<td>0.34</td>
</tr>
<tr>
<td>135</td>
<td>0.81</td>
<td>0.48</td>
<td>0.50</td>
</tr>
<tr>
<td>155</td>
<td>0.88</td>
<td>0.48</td>
<td>0.55</td>
</tr>
<tr>
<td>175</td>
<td>0.80</td>
<td>0.50</td>
<td>0.69</td>
</tr>
</tbody>
</table>
Data and predicted SM background as a function of TLD cut.

TLD cut shown is optimized for $M_H=155$ GeV.

After the TLD cut we have:

- 1 $ee$ event
- 3 $e\mu$ events
- 2 $\mu\mu$ events
Results: expected and observed number of events for different Higgs masses

<table>
<thead>
<tr>
<th>$M_H$ (GeV)</th>
<th>115</th>
<th>135</th>
<th>155</th>
<th>175</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge flips</td>
<td>2.35±0.90</td>
<td>1.40±0.53</td>
<td>1.12±0.43</td>
<td>0.89±0.31</td>
</tr>
<tr>
<td>QCD</td>
<td>2.35±1.04</td>
<td>2.04±0.83</td>
<td>1.64±0.69</td>
<td>1.16±0.46</td>
</tr>
<tr>
<td>WZ</td>
<td>3.40±0.28</td>
<td>1.87±0.15</td>
<td>1.51±0.12</td>
<td>1.26±0.10</td>
</tr>
<tr>
<td>ZZ</td>
<td>0.34±0.03</td>
<td>0.21±0.02</td>
<td>0.17±0.01</td>
<td>0.15±0.01</td>
</tr>
<tr>
<td>Total</td>
<td>8.44±1.37</td>
<td>5.52±0.99</td>
<td>4.45±0.82</td>
<td>3.46±0.57</td>
</tr>
<tr>
<td>Signal</td>
<td>0.037±0.004</td>
<td>0.100±0.010</td>
<td>0.143±0.015</td>
<td>0.110±0.011</td>
</tr>
<tr>
<td>Data</td>
<td>9</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

All three channels are combined and TLD cut is optimized for best expected limit for each mass and channel individually.

Observed number of events is consistent with SM background prediction, therefore cross-section limit can be established.
Results: Expected and observed limits at the 95% C.L. for the associated Higgs boson production

<table>
<thead>
<tr>
<th>$M_H$(GeV)</th>
<th>115</th>
<th>135</th>
<th>155</th>
<th>175</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected limit (pb)</td>
<td>3.3</td>
<td>2.8</td>
<td>2.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Observed limit (pb)</td>
<td>3.2</td>
<td>2.9</td>
<td>2.9</td>
<td>2.8</td>
</tr>
</tbody>
</table>
Expected and observed limits at the 95% C.L. for the associated Higgs boson production
Conclusion:

• A search, using 360-380 pb has been performed for the process $WH \rightarrow WWW \rightarrow l^{\pm} l'^{\pm} \nu \bar{\nu} + X$ in the $ee, e\mu$ and $\mu \mu$ channels.

• Data events are in agreement with SM prediction.

• Upper limit on $\sigma(WH) \times Br(H \rightarrow WW^*)$ was set.

• Results of the search are being combined with other Higgs channels.
The End
Charge flip probability and $1/p_T$

Charge flips in MC

1/$p_T$ for muon flips in MC

Muons with misreconstructed charge acquire random $q/p_T$, Shape of $q/p_T$ is used to make invariant mass plot.
QCD invariant mass distribution

**ee channel**

**μμ channel**